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Toroidal Plasma Sources for Remote and Isotropic Processing

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In plasma materials processing for semiconductor fabrication, requirements for etching range from high aspect ratio anisotropic to highly selective isotropic. The latter, which includes chamber cleaning, is typically performed with remote plasma sources capable of producing large fluxes of halogen or oxygen radicals. The remote nature of the plasma source is intended to minimize the fluxes of charged particles or UV photons onto the wafer. Toroidal plasma sources (TPS) represent a class of devices that are capable of sustaining high powers in highly attaching gases [1]. A TPS typically consists of a ferrite core with a primary winding located outside the plasma reactor [2]. The plasma reactor is configured to provide a closed plasma loop that acts as the secondary winding to the ferrite core. Typical operating conditions are up to several kW power deposition, flow rates of up to several slm and pressures of up to 10 Torr with gas mixtures containing halogen donors such as NF_3.

In this paper, results from a computational investigation will be discussed of the fundamental properties of toroidal plasma sources sustained in Ar and Ar/NF_3 mixtures. These investigations were performed using the Hybrid Plasma Equipment Model (HPEM) [3]. In conventional inductively coupled plasmas, the induced electric field in the plasma is in the azimuthal direction. For 2-dimensional models this electric field is perpendicular to the plane of interest, and so typically appears only as a heating source. In a TPS, the induced electric field is in the plane of interest. To facilitate these conditions, a new capability was developed to represent the transfer of magnetic fields through the ferrite core from the primary and to secondary, and propagation of the secondary induced electric field in the x-y plane.

The base case operating conditions are 1 Torr of Ar/NF_3 mixtures flowing at 500 sccm with a power deposition of 1 kW at 500 kHz. Typical plasma conditions are shown in Fig. 1 for Ar and NF_3 only gas mixtures. To enable high power deposition beyond the capabilities of a single ferrite core, dual ferrite cores are used. Although the ideal TPS has closed-loop symmetry for power deposition in the x-y plane, when using dual sources this close-loop symmetry is broken. The end result is two parallel regions of power deposition. This distribution of power produces two lobes of electron density of approximately 2×10^{13} cm^{-3}. When operating in NF_3, the asymmetric power deposition produces sub-sustaining

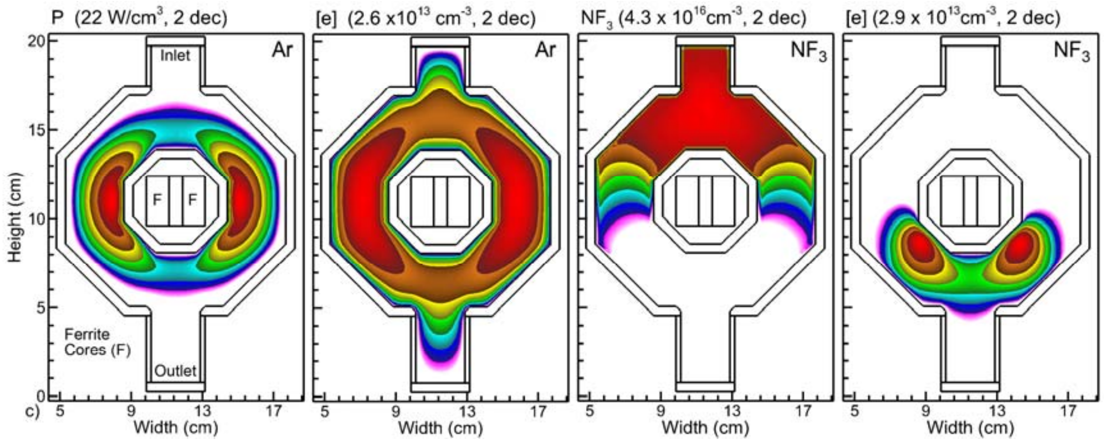

Fig. 1 : Properties of a dual-ferrite, remote toroidal plasma source with 1 kW power deposition at 500 kHz (left) Ar plasma: power and electron density. (right) NF_3 plasma: NF_3 density and electron density

electric fields near the inlet where the highly attaching NF_3 enters into the chamber. After a start-up transient, the plasma stabilizes lower in the reactor where the NF_3 dissociation has produced a less attaching environment. In this case the NF_3 is fully dissociated to produce dominantly a stream of NF, F and N. The gas temperature is several thousand degrees, resulting in a significant fraction of the dissociation being thermal. Results will be discussed for parametric studies for power, gas mixture and frequency.

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